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CONSTRUCTION AND EVALUATION OF EFFECTIVE DEAD SPACE COMPARATOR

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Washington, D. C.

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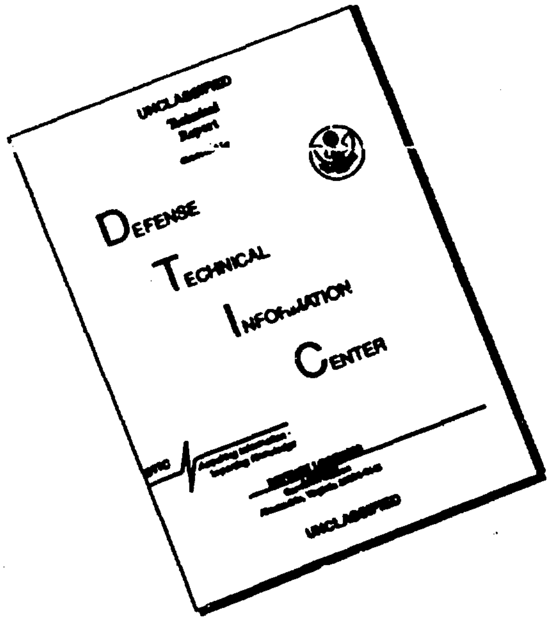

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A device for comparing the Effective Dead Space (EDS) of various breathing systems and components was fabricated. Apparatus consisted of two electrically driven bellows, one of which "exhaled" 100% oxygen into the system or component (e.g. mouthpiece, facemask) being tested, next the second bellows "inhaled" air from the same system and "exhaled" it into a spirometer.

By determining the amount of oxygen in the sample in the spirometer it was

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20. possible to calculate the fraction of each "exhaled" breath that was "inhaled". This figure expressed in cc. was called the E.D.S. A sample of 10 "breaths" was collected for each determination. The validity of this procedure was tested by measuring the E.D.S. of 1 to 6 foot lengths of rubber tubing. E.D.S. was studied in 13 different systems and components. Reasonable and reproducible values were obtained when the comparator was operated at a rate of 14-20 breaths/min. with a Tidal Volume of 2000 cc.

Mechanical improvement is required to render the comparator suitable for measurements of E.D.S. at breathing rates above 20/min. The significance of E.D.S. values obtained with Tidal below 2000 cc. requires further investigation. E.D.S. comparisons can be employed as a figure of merit in the design and evaluation of underwater breathing systems and components.

SUMMARY

Problem

To construct and evaluate a mechanical device suitable for measuring the fraction of each exhaled breath which is inhaled on the succeeding breath. This value is known as the Effective Dead Space and is of significance in the design and evaluation of respiratory equipment since the greater the Effective Dead Space the greater will be the amount of carbon dioxide in the air actually reaching the lungs.

Findings

(a) The comparator has been constructed and found suitable for measuring effective dead space within a certain range of breathing rate and tidal volume.

(b) Measurement of effective dead space in certain breathing components has been accomplished with satisfactory results.

(c) Further work with the comparator is advised.

(d) Certain mechanical aspects of the comparator need improvement.

Recommendations

(a) Employ Effective Dead Space measurements, using a breathing rate of 14-20 breaths per minute and tidal volume of 2 liters, as a routine part of the evaluation of breathing systems and components.

(b) Correct mechanical defects of the comparator.

(c) Consider procurement of a second "basic breathing machine".

(d) Consider procurement of a mechanical breather of different design.

ADMINISTRATIVE INFORMATION

Ref: (a) Conference O-in-C, Experimental Diving Unit and CDR Gresley, BuShips, (Code 288)

Reference (a) covered all administrative details leading up to the work reported here.

L. R. FUNDERBURK, Jr., HM1, USN was assigned as assistant project engineer to schedule and record the results of tests.

Manpower requirements for the work in this project were as follows:

Planning		70
Testing		250
Reporting		64
	TOTAL	384

Work commenced November 1956 and completed January 1957. Costs were charged to project order 300 38/57.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

1. Objective

1.1 Introduction

1.1.1 Dead space is undesirable in underwater breathing apparatus, principally because it impairs elimination of carbon dioxide. Exhalation fills the dead space with carbon dioxide laden alveolar gas which returns to the lungs during the following inhalation. The volume of alveolar gas re-inhaled in this way is called the effective dead space. Simple volumetric measurement of a space believed to be "dead" does not give the effective dead space volume because some of the pockets of the specs do not flush completely during the breathing cycle. The most promising approach to accurate measurement of effective dead space appears to be functional method employing a special mechanical analog of the human respiratory system.

1.1.2 Construction of such an analog will permit evaluation of its accuracy. A satisfactory degree of accuracy will permit direct comparison of masks and other components of breathing systems to determine relative effective dead space and to select satisfactory equipment by whatever standards physiological studies in dead space may establish.

1.2 Objective

1.2.1 The objectives of this project were:

(a) Construct and test a special mechanical analog of the human respiratory system, hereafter called effective dead space comparator, capable of measuring effective dead space volume in various types of underwater breathing equipment.

(b) Construct the comparator in such a package that it may be retained as a laboratory instrument.

(c) Report the project in such a manner as to permit referring to the report in justification of any subsequent statements of effective dead space volume as measured by the comparator.

1.3 Scope

1.3.1 The scope of this project was limited to evaluation of the comparator and the determination of dead space in a number of breathing components. No attempt was made to establish any physiological standards during this evaluation.

2. Description

2.1 Principle

2.1.1 If a man exhales through a dead space, he leaves a certain amount of alveolar gas in that space. On the subsequent inspiration he re-inhales some of this gas. The volume of exhaled gas which he re-inhales is the effective volume of dead space (in contrast to the actual volume, which may be larger if it has "pockets"). If the concentration of carbon dioxide in the exhaled

alveolar gas is known, collecting, mixing, and analyzing the entire inspired volume would give the data necessary to determine effective dead space volume by simple calculation. This procedure cannot, however, be conducted in a human subject.

2.1.2 A mechanical system can easily provide the conditions necessary to duplicate respiration and determine effective dead space. A "breathing machine" which has two separate "lungs" can use one to exhale a known concentration of a specific gas through the breathing circuit being tested, and the other to inhale fresh air through that circuit, delivering the inhaled gas to a collecting system.

2.2 Apparatus

2.2.1 The apparatus is basically a modification of the Mine Safety Appliances breathing resistance tester in use at the Experimental Diving Unit. The modification is a not-too-readily removed attachment, used in conjunction with a Beckman Oxygen Analyzer, a spirometer, and the necessary valves and connections. Figure 1 shows the proper assembly of the comparator.

2.3 Operation

2.3.1 A linkage connects bellows (A) and bellows (B) so that both bellows must always move in the same direction by the same amount. A rotating eccentric (G) drives both bellows simultaneously. Bellows (A) draws pure Oxygen from a demand regulator (J), and "exhales" it through automatic check valve (C) into the apparatus under test, mounted at (K). Valve (C) is open when bellows (A) "exhales" and closed when it "inhales". Bellows (B) "inhales" from the apparatus under test through an automatic valve (D) which opens on "inhalation" and closes on "exhalation". Bellows (B) discharges through a second check valve (F) to the collecting system (L).

2.3.2 Automatic check valves (C) and (D) are opened by vacuum and closed by pressure. These work in conjunction with a solenoid-operated tube-pinching device (O) and Micro Switch (I). (Other types of low-resistance mechanical or electrical valving systems would presumably serve the same purpose if properly synchronized with the breathing of bellows (A) and (B).) See fig. 1.

2.4 Gas Collection

2.4.1 Bellows (B) discharges through check valve (F) into the spirometer (L). Three-way valve (E) provides a means for by-passing the discharge of bellows (B) when a sufficient quantity has been collected in (L).

2.5 Gas Analysis

2.5.1 A Beckman Model D (0 - 100%) oxygen analyzer was connected to a stopcock (N) on the spirometer (L). Gas was forced through the analyzer by application of weights to the bell of the spirometer.

3.1 Single Breath Calculation

3.1.1 Single breath calculations were originally scheduled in this project, but they were found impractical and discontinued.

3.2 Multiple Breath Calculation

3.2.1 Multiple breath calculations were used throughout the entire project. After flushing the system, 10 breaths were collected in the spirometer, volume noted, and oxygen content analyzed. This procedure was repeated until 3 consecutive readings yielded the same values for both volume and oxygen percentage.

3.2.2 The formula employed in multiple breath calculations is defined as follows:

$$DS - \frac{A}{B}\left(\frac{X-20.94}{100-20.94}\right) - W$$

Where:

DS - Effective Dead Space of test object

A - Collected gas volume

B - Number of breaths considered

X - Collected gas oxygen percentage

20.94 - Percentage of oxygen in atmospheric air

100 - Percentage of gas introduced into test object by bellows (A) (assumed 100% oxygen)

W - Dead Space of comparator

3.3 Dead Space of Comparator

3.3.1 Since the comparator has some dead space in the connecting tubes, its own effective dead space had to be determined before any breathing components could be measured. The measurements of comparator dead space was accomplished by the same procedure as described in 3.2.1, employing the same formula. In this case, no test object was attached, and W in the formula was assumed to be zero.

3.4 Flushing Machine

3.4.1 Before each run was conducted the comparator was allowed to take 15-20 breaths. This was considered adequate to insure complete flushing of the system. Any variation in the next 3 consecutive readings for oxygen percentage of collected gas (3.2.1) was indication of incomplete flushing.

3.5 Known Standards

3.5.1 To investigate the probable accuracy of the method, when determining dead space with the comparator, known standards were substituted for the dummy head at (K). These standards consisted of 6 sections of smooth bore spirometer tubing with one inch inside diameter. Lengths of 1, 2, 3, 4, 5, and 6 feet were used (see figure 11). Water volumes of these sections were measured carefully and recorded. A Y-fitting with 2 check valves (See 5.1.4) was installed at the end of each portion being tested (Fig. 12).

3.5.2 The determination of effective dead space in the six sections of tubing was accomplished by the multiple breath method. Determination for W (comparator dead space) during these runs included the 2-way check valve. (Fig. 12)

3.5.3 A rate of 20 breaths per minute and tidal volumes of .5, 1 and 2 liters were used during determinations of effective dead space in known standards.

3.6 Breathing Components to be tested

3.6.1 Listed below are the breathing components tested. Most of these are widely used within the U. S. Navy.

(a) Scott Hydro-Pak, Navy Model, complete system (Fig. 2)

(b) Lambertsen-LARU mask, including tubes and check valves. (Separate measurements of the components of this assembly were also made), Fig. 3.

(c) U. S. Divers Aqua-Lung, complete syste, Navy Model, (Fig. 4).

(d) Mine Safety Appliances Mask "Bugeye" with integral check valve arrangement, (Fig. 5).

(e) Scott Universal Mask, without mouthpiece; no check valves used, (Fig. 6).

(f) DESCO Lightweight Diving Mask "Jack Brown" (without normal air-hose supply -- inspired air from atmosphere through integral check valves), (Fig. 7).

(g) Scottoramic mask, (Fig. 8).

(h) Northill Air-Lung, complete system, (Fig. 9).

(i) Mouthpiece and hoses with check valves at far ends. (Arrangement similar to that of the Draeger closed-circuit Scuba), (Fig. 10).

3.6.2 Determination of effective dead space in breathing components was accomplished by the multiple breath method, as outlined in 3.2.

3.6.3 Determination for W during tests of all masks included a one inch inside diameter tube passed through dummy head (K).

3.6.4 Different breathing rates and tidal volumes were employed during tests of breathing components. The Scott Hydro-Pak, Lambertsen LARU and aqua lung were tested with the following rates and volumes.

(a) 20 breaths per minute, 2 liters per breath.

(b) 14 breaths per minute, .5 liters per breath.

(c) 26 breaths per minute, .5 liters per breath.

(d) 26 breaths per minute, 3 liters per breath.

(e) 14 breaths per minute, 2 liters per breath.

All other components were tested only at a tidal volume of 2 liters and breathing rate of 20 breaths per minute.

4. Results

4.1 Effective Dead Space of Known Standards

4.1.1 Table 1 shows the results of effective dead space measurements on the straight tubes employed as known standards.

4.1.2 With breathing rate set at 20 breaths per minute and tidal volume set at 2 liters, the effective dead space measured by comparator was approximately equal to the water volume. The average error of all 6 sections of spirometer hose was 13.5 cc. or 6.05 percent. Note, however, that treating each section of hose individually, the percentage of error decreases as the length of tubing becomes longer.

4.1.3 With breathing rate set at 20 breaths per minute and tidal volume set at 1 liter, the effective dead space as measured by the comparator approximated the water volume only on the 1 and 2 foot sections of tubing.

4.1.4 With breathing rate set at 20 breaths per minute and tidal volume set at .5 liters, all the effective dead space measurements are considerably lower than the water volumes.

4.2 Effective Dead Space of Breathing Components (Table 2)

4.2.1 With the breathing rate set at 20 breaths per minute and tidal volume set at 2 liters the effective dead space of breathing components as measured by the comparator closely approximated the water volume in some cases and was considerably less in others.

4.2.2 With the breathing rate set at 14 breaths per minute and tidal volume set at 2 liters the effective dead space of breathing components as measured by the comparator closely approximates the water volume in some cases and was considerably less in others.

4.2.3 With the breathing rate set at 26 breaths per minute and tidal volume set at 3 liters, effective dead space of breathing components as measured by the comparator was consistently higher than the water volume.

4.2.4 With breathing rate set at 14 breaths per minute and tidal volume set at .5 liters, no effective dead space values were obtained on any of the components.

4.2.5 With breathing rate set at 26 breaths per minute and tidal volume set at .5 liters, the effective dead space volumes were consistently higher than the measured water volumes.

4.2.6 Measurements on the Scott Hydro-Pak show:

(a)	Water volume	- 670 cc.
	Effective Dead Space	- 640 cc.
	Difference	- 30 cc.

4.2.7 Table 3 presents results obtained with the Lambertsen LARU mask and its components.

4.2.8 Mine Safety Appliances (Bugeye) measured as follows:

(a)	Water volume	-	500 cc.
(b)	Effective dead space	-	336
(c)	Difference	-	164 cc.

4.2.9 Desco ("Jack Brown") mask measured as follows:

(a)	Water volume	-	750 cc.
(b)	Effective dead space	-	646
(c)	Difference		104 cc.

4.2.10 Scott Scottoramic mask measured as follows:

(a)	Water volume (Mask alone)	800 cc.
(b)	Water volume of tubing	85
(c)	Water volume of mask and tubing	885 cc.
(d)	Effective Dead Space of mask and tubing	787 cc.
(e)	Difference	98 cc.

4.2.11 Scott Universal mask measured as follows:

(a)	Water volume	930 cc.
(b)	Effective dead space	860
(c)	Difference	70 cc.

NOTE: Water volumes of the 3 breathing components listed next were measured at 550 cc. each. **However,** this is not all dead space and consequently the water volumes have no direct relationship to the effective dead space.

4.2.12 The Aqua Lung unit measured as follows:

(a) Effective dead space 146 cc.

4.2.13 The Northill unit measured as follows:

(a) Effective dead space 354 cc.

4.2.14 The mouthpiece, hoses and check valves measured as follows:

(a) Effective dead space 164 cc.

5. Discussion

5.1 Accuracy of Method

5.1.1 Straight tubing was used as a test of accuracy because water volume and effective volume should theoretically be almost identical provided that reasonably complete washout occurs with each breath. Results indicated that:

(a) Low tidal volumes consistently yielded values lower than the actual volume of tubes. This was true unless the tidal volume was approximately twice the size of the tube volume.

(b) High rates (above 20 breaths per minute) constantly yielded effective dead space values higher than the rated volumes.

(c) In the case of 2 liters per breath, 20 breaths per minute measurements, close approximation of effective dead space was obtained.

5.1.2 The low tidal volumes presumably gave low effective dead space values because the "alveolar" gas was not completely washed into the collecting system, while a certain amount of fresh air came through even though the tidal volume was considerably less than the tubing volume. In any tube, the air velocity is greater in the center than at the sides, so a "spike" of fresh air will reach the opposite end of the tube considerably before all of the original gas has been washed through.

5.1.3 Abnormally high values obtained while running the comparator at high rates were presumed due to automatic valves (C) and (D) being out of phase with the breathing cycle. This was a function of the time required to close the valves by pressure and open them by vacuum. Due to the increased resistance to breathing through the test object at high rates, oxygen was drawn from demand regulator (J) past valve (C) which should have been closed, into bellows(B) without having passed through the test object. This caused the percentage of oxygen in the collected gas to rise and give falsely high values for effective dead space. High rates of breathing rather than large tidal volumes were believed responsible for this phenomenon.

5.1.4 Prior to the addition of the y-fitting and check-valves (3.5.1), results with the known standards were not reproducible. It was believed that diffusion or mixing of fresh gas into the open end of the tube reduced the effective dead space. On the other hand, re-inhalation of exhaled gas lingering at the open end appeared capable of increasing the value obtained. Which of these effects predominated depended largely upon the amount of air-movement in the area. In still air, the effective dead space often exceeded the volume of the tubes; with an electric fan in the vicinity, it fell far below this value. Separation of the inspiratory and expiratory streams eliminated this source of variation. With one possible exception (5.3.4), it was not believed to be significant in determinations with any of the test objects.

5.1.5 At low rates and tidal volumes effective dead space of equipment employing demand regulators could not be measured. Comparator bellows (B) appeared to be so flexible that it could not develop enough negative pressure to open a demand regulator under these conditions. Consequently, it was not possible to move gas through the system.

5.2 Breathing Components

5.2.1 The figures shown in Table 2, suggest that only the values obtained with rates of 14-20 breaths per minute and tidal volumes of 2 liters are sufficiently accurate to be accepted.

5.2.2 Results obtained from rates and tidal volumes settings other than those mentioned in 5.2.1 are considered highly inaccurate. Reasons for these inaccuracies are discussed in 5.1.2 and 5.1.3.

5.3 Characteristics of Masks

5.3.1 Superficial examination divides the masks tested into two groups: those which have a single "faceplate" (Scott Hydro-Pak, Desco, Scott Universal and Scottoramic) and those in which separate eyeports are provided (LARU, Mine Safety Appliances). Except in the Scottoramic, the former have the inspiratory connection on one side and the outlet on the other while the latter group uses a central connection serving both purposes. The eyeport arrangement also permits closer conformation of the mask to normal facial contours.

5.3.2 Water volume measurements indicate that the internal volume of the "eyeport" type is considerably less than of the "faceplate" group, as might be expected.

5.3.3 The comparator measurements indicate that all masks in the faceplate group have effective dead space of at least 85 percent of the water volume. In the two eyeport masks, the effective dead space is 60 percent and 67 percent of the water volume, respectively. This difference may be attributed to the fact that the flow of gas to and from the mouth is more direct tending to be funneled to a central connection, and that there is less tendency for the entire volume to be filled with alveolar gas on expiration and flushed with incoming air on inspiration. In the Mine Safety Appliances mask, inspired gas enters through openings under the eyeports and would tend to mix with gas in the mask volume as a whole, but expired gas should go rather directly to the central connection. The smaller water volume, coupled with the smaller proportion of this which is effectively dead gives the eyeport masks a considerably smaller effective dead space than the faceplate group. In the case of the LARU mask, the addition of a non-channeled shut-off valve, "T" and tubing necessarily increases the effective dead space. In the Mine Safety Appliances mask, the fact that the "T" assembly itself is divided into inspiratory and expiratory channels reduces this addition to some extent.

5.3.4 The Scottoramic mask has a single faceplate, but it shares the central arrangement of inspiratory and expiratory connections noted in eyeport masks. The Effective dead space, as measured, was very high; but a check valve should have been placed in the inhalation tube to prevent expiratory gases from passing back through it. Failure to do this probably added about 100 cc to the effective dead space, possible more because of the phenomenon

noted in section 5.1.4. It also prevented the normal separation of inspired and expired streams (similar to that in the Mine Safety Appliances mask), and this also may have increased the apparent proportion of effective dead space. The necessity for using the basic mechanism of the comparator for other purposes prevented restudying this mask when the defects of the original measurements were noted.

5.3.5 Owing to each mask having its own unique characteristics, effective dead space could not be accurately predicted by placing the mask in one of the two categories mentioned. Measurement with the comparator seems to be the only logical way of taking all these characteristics **into** consideration.

5.4 Mouthpiece Systems

5.4.1 In most systems employing a mouthpiece and breathing tubes, dead space can be reduced to a minimum by incorporating inspiratory and expiratory check valves in the mouthpiece connection or in the tubing close to the mouthpiece. In these cases, the effective dead space should be approximately equal to the water volume of the small space involved. In some cases, such an arrangement is considered less convenient than placing the valves at the far ends of the tubes or allowing the demand valve assembly itself to serve this function. The comparator study with mouthpiece arrangement of this type was undertaken to determine how much effective dead space was present under these conditions.

5.4.2 The effective dead space values obtained with the "Draeger" arrangement (Fig. 10) and the Aqua-Lung were both in the neighborhood of 150 cc. The average volume of a valved mouthpiece connection would not be likely to exceed 40 cc., so it appears that mixing and gaseous diffusion in the tubes contributed somewhat over 100 cc. to the effective dead space of these systems. The reverse displacement of the demand valve diaphragm on exhalation in the Aqua-Lung may permit some movement of expired gas into the inspiratory tube, but this does not appear important in contributing to dead space.

5.4.3 When the Northill Air-Lung regulator was used with this mouthpiece arrangement it yielded a markedly higher effective dead space: and this requires some explanation. This may be provided by the fact that this regulator requires negative pressure through the exhalation tube to open the valve. It is possible that the arrangement somehow permits a significant amount of alveolar gas from this tube to be rebreathed. Newer models of the Northill Air-Lung provide check valves at the mouthpiece with only a small hole in the expiratory check to permit transmission of the required negative pressure. This arrangement may eliminate the high effective dead space.

5.4.4 Prediction of dead space in any mouthpiece system by visual analysis would be a highly inaccurate method. The unique characteristics of each separate piece of equipment demand measurements by a method similar to that of the comparator.

5.5 Tidal Volumes and Dead Space

5.5.1 As noted in section 5.1.2, low tidal volumes consistently yielded lower values for effective dead space than would be expected on the basis of water volume and values obtained with larger breaths. This is in accord with the results of physiological studies on patients with severely depressed respiration who were found to have some effective ventilation in spite of

tidal volumes smaller than their normal dead space. Explanations on the wash-out pattern of tubing and diffusion at the interface appear to be adequate. The low values for effective dead space obtained at low tidal volumes are very likely correct ones from the physiological standpoint, under the stated conditions. Difference in configuration may cause exhaled gas to pocket. Low rates and tidal volumes may not completely wash out these pockets. Consequently, a lower dead space determination is obtained.

5.5.2 The "plateau" of effective dead space values obtained when the tidal volume of the comparator is above a certain point is of primary interest in comparing the effective dead space of various breathing systems components. From the standpoint of a working diver, such values are certainly the important ones. However, it is worthwhile to consider whether such measurements alone are completely adequate. On some occasions, all diving rigs are used by men who are nearly at rest and whose tidal volumes are small. It might be found that a difference in the configuration of components caused an important difference in their effective dead space at low tidal volumes even though the "plateau" values were similar. This possibility should at least be investigated.

5.6 Continuous Air Flow and Dead Space

5.6.1 The Desco mask (Jack Brown) is normally used with an airhose and a continuous flow of gas from the inhalation side and out the exhalation side. Since this would tend to keep the internal volume of the mask flushed with fresh air, the dead space should be much lower than as measured without this flow. An attempt was made to determine effective dead space with minimal continuous flow through this mask, which would represent the maximum effective dead space in normal use, but this was not successful. Any "faceplate" mask with the inhalation and exhalation connections on opposite sides should have its effective dead space reduced by any degree of continuous circulation. For some applications, this fact will have to be considered in comparator studies.

5.7 The Comparator as a Packaged Unit

5.7.1 The objective of constructing the comparator as a practical packaged unit to be kept in the laboratory and used as an accessory to the breathing resistance tester was not reached successfully. It was found that availability of the tester, moving it and assembling and disassembling the comparator attachments and accessories presented much more of a problem and involved much more time than was anticipated. Having a separate basic breathing machine and establishing the comparator as a semi-permanent unit would be much more practical.

6. Conclusions

6.1 Conclusions

6.1.1 The following conclusions are drawn from the evaluation of the effective dead space comparator:

(a) The design of the comparator is basically sound. However, its use as a packaged accessory to the Mine Safety Appliances Breathing Resistance Tester is not practical. (5.7.1)

(b) Reasonable and reproducible values for effective dead space are obtained when the comparator is operated at 14 to 20 breaths per minute and a tidal volume of 2 liters. (5.1.1 (c) (5.2.1)

(c) With present arrangements, the comparator is not suitable for effective dead space measurements at high rates of breathing. (5.1.1 (b) 5.1.3)

(d) The significance of effective dead space values obtained with tidal volumes below 2 liters requires further investigation.

6.1.2 Application of the comparator to various breathing circuits and components leads to the following conclusions:

(a) The effective dead space of a mask may be considerably smaller than its internal volume. Although the effective dead space-volume relationship is related to the arrangement of entry and exit connections, it could not be predicted simply by inspection. (5.3.3)

(b) The effective dead space of mouthpiece systems is particularly difficult to predict from volume measurements and analysis of the circuit. (5.4.2)

(c) Accurate determinations of effective dead space would be difficult or impossible to accomplish without the comparator or some similar device. (5.3.5, 5.4.4)

6.2 Recommendations

6.2.1 The following recommendations are submitted concerning applications of the comparator:

(a) Employ measurement of effective dead space with the comparator as a routine part of the evaluation of all breathing systems and components to which it can be applied.

(b) For routine measurements, employ a respiratory rate in the range between 14 and 20 breaths per minute and a tidal volume of about 2 liters. (5.1.1 (c))

(c) Particularly if the present equipment is improved (6.2.2), investigate the possible significance of values obtained with other rates and tidal volumes. (5.5.1)

6.2.2 The following recommendations are submitted concerning the comparator itself:

(a) Replace automatic valves (C) and (D) (fig. 1) with suitable electric solenoid valves.

(b) Obtain a second basic "breathing machine" to obviate the conflicts and time-loss involved in using the same apparatus for both the breathing resistances and dead space studies. (5.3.4)

(c) Consider procurement of a mechanical breather of entirely different design, having less "elasticity" (5.1.5) and with integral arrangements for use as an effective dead space comparator.

TABLE I

DEAD SPACE DATA ON KNOWN STANDARDS

SIZE TUBING	TIDAL VOLUME	BREATHING RATE (BPM)	LITERS OF COLLECTED VOLUME (10 BREATHS)	TOTAL DEAD SPACE	MACHINE DEAD SPACE	TUBING DEAD SPACE	WATER VOLUME (cc)	ERROR (cc) + or -	ERROR PERCENTAGE + or -	OXYGEN PERCENTAGE Corrected
6 feet	2	20	20.688	1179.0	269.9	912.2	940.0	-27.8	-2.9	66.0
6 feet	1	20	10.017	906.7	241.5	665.2	940.0	-295.0	-31.38	92.5
6 feet	.5	20	5.081	488.8	257.5	231.4	940.0	-709.0	-75.4	97.0
5 feet	2	20	20.688	1035.2	267.9	767.3	765.0	+2.3	+.3	60.5
5 feet	1	20	10.017	843.4	241.5	601.9	765.0	-68	-10.8	87.5
5 feet	.5	20	5.081	475.9	257.5	218.4	765.0	-547	-71.5	95.0
4 feet	2	20	20.616	904.7	267.9	638.8	625.0	+15.8	+2.5	55.25
4 feet	1	20	10.017	799.0	241.5	557.1	625.0	-68.0	-10.8	84.00
4 feet	.5	20	5.081	453.5	257.5	196.5	625.0	-429.9	-68.6	91.5
3 feet	2	20	20.543	735.6	267.9	467.7	455.0	+17.7	+3.9	49.25
3 feet	1	20	10.017	558.9	241.5	317.5	455.0	-138.0	-30.2	65.0
3 feet	.5	20	5.081	459.9	257.4	202.5	455.0	-198.0	-43.5	92.5
2 feet	2	20	20.398	618.7	267.9	350.8	310.0	+40.8	+13.2	45.0
2 feet	1	20	10.017	532.9	241.5	291.4	310.0	-19	-6.1	63.0
2 feet	.5	20	5.081	418.1	257.5	160.7	310.0	-150	-43.3	86.0
1 foot	2	20	20.398	453.0	269.9	185.1	155.0	+30.13	+19.4	32.25
1 foot	1	20	10.017	399.9	241.5	157.4	155	-2	-1.2	52.5
1 foot	.5	20	5.081	353.9	257.5	96.4	155	-59.0	-38.0	76.0

TABLE II

DEAD SPACE DATA ON BREATHING COMPONENTS

RIG	TIDAL VOLUME	BREATHS PER MINUTE	COLLECTED VOLUME 10 BREATHS LITERS	OXYGEN PERCENT CORRECTED	TOTAL DEAD SPACE (cc)	MACHINE DEAD SPACE (cc)	RIG DEAD SPACE (cc)	WATER VOLUME OF RIG (cc)
HYDRO PAK	2	20	20.398	53.25	833.59	178.2	655.4	670.0
HYDRO PAK	.5	26	5.517	70.0	342.3	99.0	243.3	670.0
HYDRO PAK	3	26	30.488	49.5	1101.3	326.9	774.4	670.0
HYDRO PAK	2	14	20.470	52.0	804.18	178.2	625.3	670.0
LAMBERTSEN	2	20	20.470	45.0	623.0	178.2	444.8	520.0
LAMBERTSEN	.5	14	5.299	68.0	315.4	99.0	216.4	520.0
LAMBERTSEN	.3	26	30.488	50.5	1139.9	326.9	813.0	520.0
LAMBERTSEN SUBMERGED	2	20	20.415	55.75	898.9	480.0	418.9	520.0
LAMBERTSEN "T" AND TUBES	2	14	20.760	33.5	329.8	163.0	166.8	"T" ONLY 65.0
LAMBERTSEN MASK ALONGE	2	**20**	20.970	40.0	500.48	163.0	337.48	
AQUA LUNG	2	20	19.019	31.5	254.0	112.0	142.0	
AQUA LUNG	.5	26	4.109	50.25	152.33	99.0	53.3	
AQUA LUNG	3	26	30.488	51.5	1178.5	326.9	851.5	
AQUA LUNG	2	14	19.744	31.5	263.7	112.0	151.7	
M.S.A. BUGEYE	2	20	20.543	40.75	514.7	178.2	336.5	500.0
SCOTT UNIVERSAL	2	20	20.761	60.5	1038.8	178.2	860.6	930.0
JACK BROWN	2	20	20.325	53.0	824.2	178.2	646.0	750.0
SCOTT SCOTTORAMIC	2	20	20.460	58.25	966.0	178.2	787.9	800.0
NORTHILL	2	20	19.890	39.5	466.9	112.0	354.9	
DRAEGER ARRANGEMENT	2	20	20.616	55.75	898.9	480.0	418.9	

TABLE III

Water Volumes	
Mask with "T", tubes, and check valves	670 cc.
Mask alone	520

"T" and tubes	150 cc.
"T" only	65

Tubes	85 cc.
Effective Dead Space	
Mask with "T" , tubes and check valves (in air)	
(average of 14 and 20 breaths per minute runs)	454 cc.
Same, Submerged	419

Reduction of dead space due to submergence	35 cc.
"T", tubes and check valves only	167 cc.
Mask only (in air)	337 cc.*

NOTE:

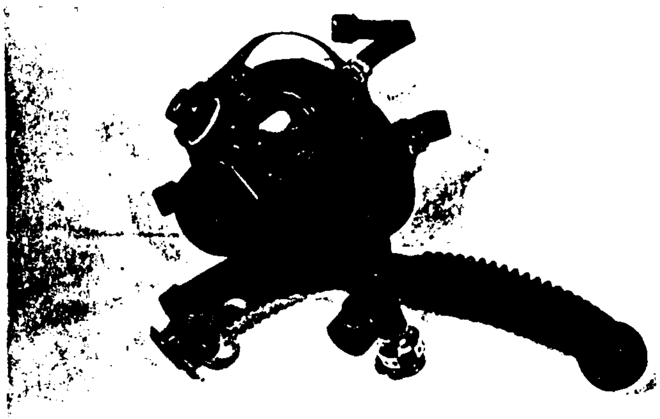
(a) Slight reduction in dead space due to submergence.

(b) Effective dead space is 183 cc. less than water volume.

*Note that this value is 50 cc. larger than that obtained by subtracting effective dead space of "T", tubes and check valves from that of complete assembly.

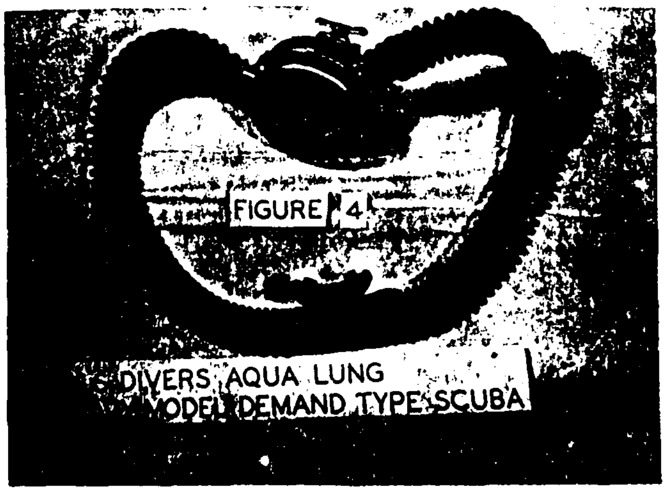
SCOTT HYDRO-PAK
NAVY MODEL

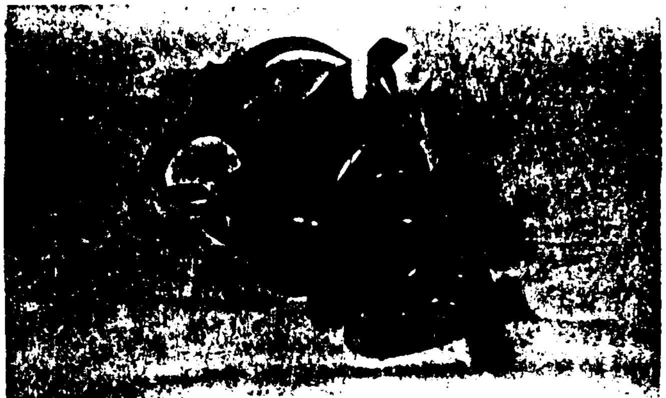
FIGURE 2



LAMBERTSEN "LARU"

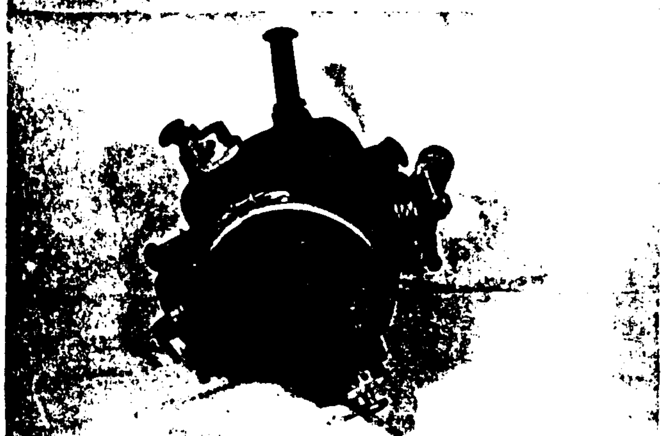
FIGURE 3





MINE SAFETY APPLIANCES
DIVING MASK (BUGEYE)

FIGURE 5

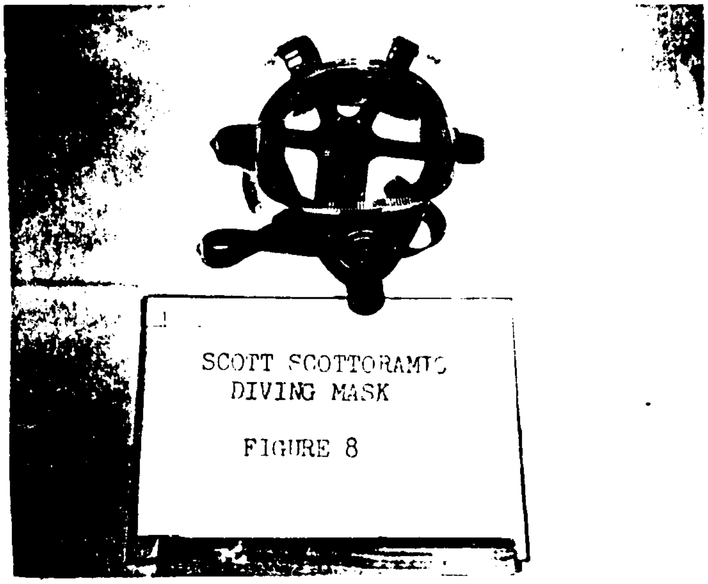


SCOTT UNIVERSAL MODEL
DIVING MASK

FIGURE 6

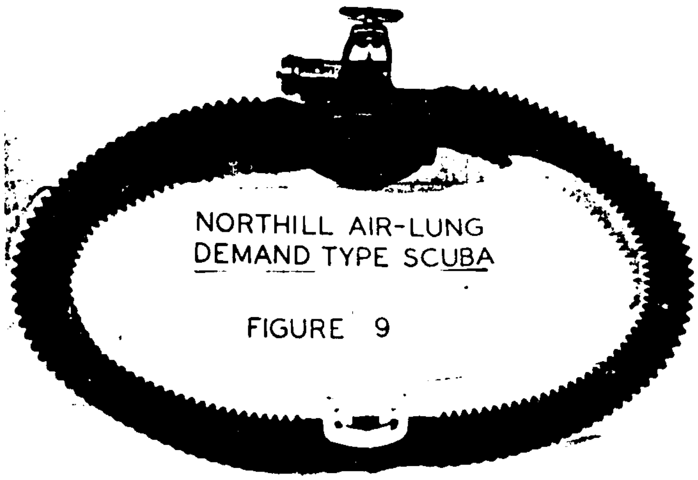
DESCO LIGHTWEIGHT DIVING MASK
(JACK BROWN)

FIGURE 7



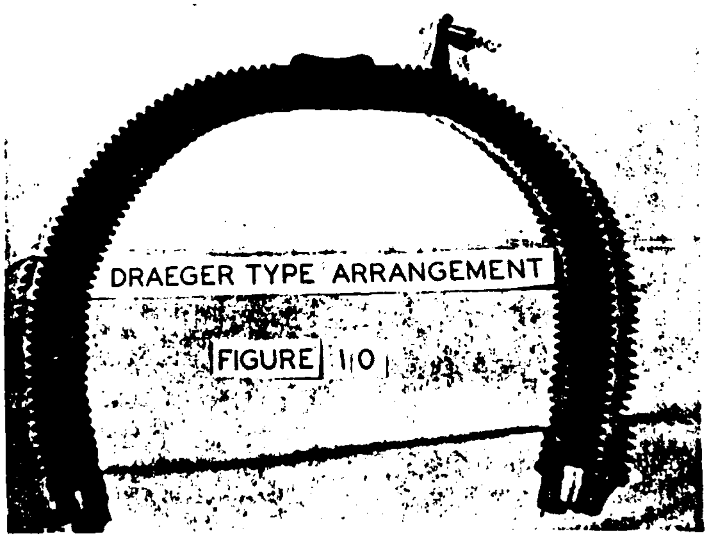
SCOTT SCOTTORAMIC
DIVING MASK

FIGURE 8



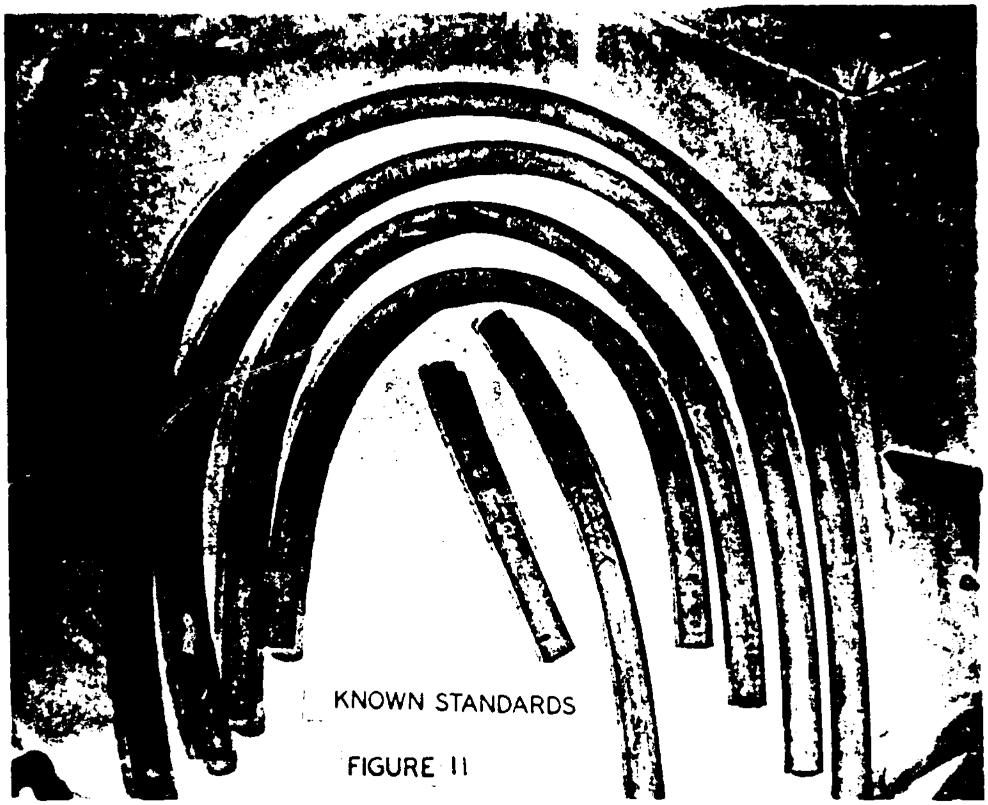
NORTHILL AIR-LUNG
DEMAND TYPE SCUBA

FIGURE 9



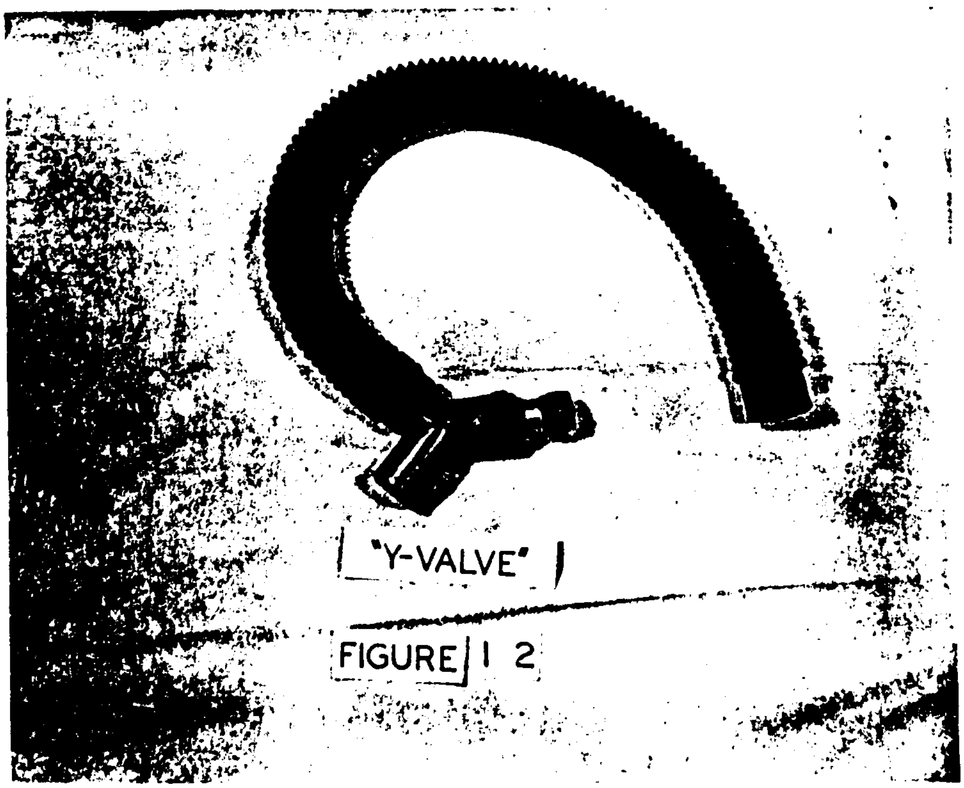
DRAEGER TYPE ARRANGEMENT

FIGURE 10



KNOWN STANDARDS

FIGURE 11



"Y-VALVE"

FIGURE 12